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Toward Sustainability Tourism: An ARDL Analysis of the Differential Impacts of International Tourism and Air Transport on CO_2 Emissions in Thailand

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ABSTRACT

This study investigates the differential impacts of international tourism and air transport on CO_2 emissions in Thailand by employing the Autoregressive Distributed Lag (ARDL) approach. Analyzing data from 1995 to 2020, the findings indicate a significant negative correlation between international tourism and CO_2 emissions, suggesting that increased tourist arrivals can lead to enhanced environmental efficiency under specific conditions. Conversely, air passenger numbers demonstrate a direct positive relationship with CO_2 emissions in the short term, pointing to the inherent greenhouse gas intensity associated with air travel. The high explanatory power of the ARDL model, with an adjusted R-squared of 0.971397, emphasizes the robustness of these results, although caution is advised in interpreting the P-values due to the potential biases from automated model selection processes. These insights contribute to the broader understanding of how tourism dynamics interact with environmental outcomes, particularly in countries like Thailand, which heavily rely on tourism for economic growth. The implications highlight the urgent need for policies that balance tourism development with sustainability mandates, ultimately guiding Thailand's trajectory toward carbon neutrality and sustainable tourism practices.

Keywords: Sustainable Tourism, International Tourism, Air Transport, CO_2 Emissions, ARDL
JEL Classifications: Q53, L93, L83, C32, R11

1. INTRODUCTION

The relationship between international tourism and its environmental impacts, specifically regarding CO_2 emissions, presents significant gaps in existing literature, particularly in the context of Thailand (Uddin et al., 2023). Although previous studies have established the prevalent negative effects of tourism on CO_2 emissions, there has been limited exploration of how different elements of tourism, such as air travel, contribute variably to environmental degradation (Liu et al., 2022). While tourism is often perceived as a contributor to pollution, some research suggests that under specific economic and regulatory conditions, it may promote greater environmental stewardship and efficiency advances (Wangzhou et al., 2022). Hence, identifying the dual impact of tourism—both as a source of emissions and a potential mitigator—represents an innovative research angle that this study aims to explore.

Moreover, the lack of localized studies focusing specifically on Thailand underscores the novelty of examining this Southeast Asian context. Many existing models and theories concerning tourism and emissions have been primarily derived from Western contexts or other Asian countries without considering the unique socio-economic and cultural aspects of Thailand (Balli, 2021). This research seeks to fill this gap by applying the Autoregressive Distributed Lag (ARDL) methodology to provide robust empirical evidence on the impact of international tourism and air transport on Thailand's CO_2 emissions.

Furthermore, earlier studies have typically operationalized variables such as international tourist arrivals, CO_2 emissions, and air passenger numbers without accounting for lag effects or temporal dependencies (Balli, 2021). The contribution of this research lies in its systematic application of time-series analysis, which enables the exploration of both immediate and delayed effects of tourism on emissions (Wangzhou et al., 2022). This temporal approach is crucial in understanding the dynamics of how tourism impacts environmental outcomes over time rather than purely correlational snapshots. The findings from this study reveal a nuanced understanding of the tourism-industry-emissions nexus, which could play a crucial role in shaping policy recommendations specific to Thailand's tourism strategies. There is a pressing need for evidence-based policy interventions to promote sustainable tourism practices that mitigate emissions while enhancing economic benefits, a gap this research aims to address through comprehensive data analysis.

2. LITERATURE REVIEW

The relationship between tourism and CO_2 emissions can be interpreted with regard to a number of macroeconomic theories, such as the Environmental Kuznets Curve (EKC), which argues for an inverted U-shaped relationship between income and environmental quality, where environmental degradation first increases with economic growth, but it improves as societies become wealthier and more environmentally conscious (Nosheen et al., 2021; Yang et al., 2021). This framework has been widely used to scrutinize the conflicts between tourism development and environmental sustainability. This hypothesis is confirmed in the literature in distinct scenarios, since although higher tourism is harmful to CO_2 emissions initially, richer nations may end up being more environmentally friendly and better at managing carbon as they get wealthier economically (Andlib and Salcedo-Castro, 2021; Balli, 2021).

Earlier studies show that the tourism industry heavily contributes to global greenhouse gas emissions, and one of the main contributors is air travel, with its direct dependence on fossil fuel (Andlib and Salcedo-Castro, 2021). It is well known that transportation, as an essential component of tourism goods and services, is a major contributor to tourism-related CO_2 emissions rather than other contributing factors related to the demand and supply sides of the tourism industry. Nevertheless, some researchers found that tourism can create environmental awareness and sustainability-based policies. Particularly in developed tourism destinations (Ozturk et al., 2023).

In Thailand, the tourism sector plays a crucial role in the economy, thus necessitating a closer examination of its impact on CO_2 emissions (Uddin et al., 2023). While previous studies have primarily focused on correlational analyses of tourism growth and emissions, there is a distinct need to apply quantitative methodologies, such as the ARDL approach, to assess how various factors interact over time (Bahar and Demir, 2023; Yaacob et al., 2023). This method allows for a nuanced understanding of not just whether tourism increases emissions, but when and how these effects manifest, frequently overlooked in existing empirical work.

Moreover, literature specifically tackling the Thailand context is scarce, highlighting the need for localized studies that factor in regional variations of tourism activity and environmental regulation effectiveness. As Thailand aims to position itself as a leading tourist destination, understanding the intricate balance between tourism growth and its ecological footprint is essential for crafting policies that facilitate sustainable development.

2.1. International Tourism

In this study, international tourism volume is measured by the number of international tourists who visit Thailand, the most important production input that measures the scale of Thailand's attractiveness to tourists (Klinsrisuk and Pechdin, 2022). This variable is important, as the income from tourism is one of the major sources of GDP for Thailand. It is related to a number of other environmental impacts, including greater levels of pollution and natural resource use caused by increased human attendance (Chulaphan and Barahona, 2021). Accordingly, the measurement of international tourist arrivals permits an improved understanding of the relationship between international tourist arrivals and CO_2 emissions. Furthermore, the changes in international tourism can affect different aspects such as the hospitality industry, local businesses, and consequently, it has an effect on the environment owing to the increasing energy required and waste produced (Zhang et al., 2019).

2.2. Air Passenger Numbers

This takes into account the total number of air passengers to and from Thailand as a measure of the relationship between air travel and CO_2 emissions. As one of the most carbon-intensive forms of mobility, the importance of assessing aviation role in international tourism and environmental sustainability could not be overstated (Leal Filho et al., 2023). The link between the rise in air travel and CO_2 emissions is well documented, with air travel regularly identified as a major contributor to greenhouse gases (Sher et al., 2021). Monitoring air traffic numbers can thus tell us much about today's recent temporary trend in tourism and in mobility patterns, and how these contribute to environmental stressors, especially in Thailand, mainly China-Abale economy, which is the most prone to environmental pressure through the paper on the Tai directly or indirectly, CO_2 (Tan et al., 2023).

2.3. CO_2 Emissions

The dependent variable in this research is CO_2 emissions. This indicator is important in evaluating the environmental damage of international tourism and air transportation in Thailand (Uddin et al., 2023). CO_2 emissions and their dynamics are essential in developing sustainable tourism policies as they are a key driver of climate change. Other studies have demonstrated that all economic activities that are mainly linked to the number of tourist arrivals give rise to high CO_2 emissions (Azam et al., 2018). As such, this variable also describes the ecological footprint of tourism-related activities and serves as an indicator of the efficiency of mitigative policy intervention addressing the reduction of carbon emissions in the tourism and transport sectors (Hasayotin et al., 2023).

3. METHOD AND DATA

3.1. Data Sources

Three key factors are studied: The number of international tourist arrivals, the number of air passengers, and CO_2 emissions (Table 1). These international tourist data consist of the total number of foreign visitors in Thailand at a daily scale from 1995 to 2020, and they provide both long-term and seasonal aspects of tourism influx. AP is defined as the total number of inbound and outbound flights for every period and measures how heavily the air traffic is used by tourists to fly in and out of the country at a particular time. The CO_2 emissions data include the sum of carbon release derived from tourism and transportation, which provides a well-defined measure of environmental impact. It has a duration of 25 years, which allows us to consider the time dynamics of each variable. This allows a holistic view capturing the evolution of the impacts on CO_2 emissions from international tourism and air transport, as well as interaction effects over time, and considering indirect effects and economic activities shaped by tourism.

To examine the impacts of international tourism and air transport on CO_2 emission in Thailand, this study applies the Autoregressive Distributed Lag approach (ARDL), which is appropriate to analyze how variables are related to each other dynamically over time. This quantitative approach allows for the short- and long-term relationships to be examined, and this analysis is important for understanding how tourism impacts CO_2 emissions for various lags (Wangzhou et al., 2022). This is of importance to us because the data used in our study are time series; therefore, the ARDL, which allows for the integration of both stationary and non-stationary data, is extremely useful.

3.2. Econometric Model

The econometric model used in this paper adopted the ARDL model to examine the dynamic relationship among international tourism, air transportation, and CO_2 emissions in Thailand. This model is known to be powerful in specific analysis of both stationary and non-stationary time series data, providing a tool to investigate both short-run and long-run relationships among the variables of interest (Hariyadi et al., 2025). The broad specification of the ARDL application combines monthly lags of each independent variable to test dependencies over time that affect CO_2 emissions. In particular, the model can be written as:

$$CO_2t = f\,(ITt, AP\ t, RECt,)$$

Where CO_2t refers to CO_2 t emissions, International Tourism and Air Passengers refer to tourism and air passenger numbers for the current and previous years. This can also enable the model to capture the interactive dynamics and cause-and-effect of the environmental impacts due to tourism in Thailand (Hariyadi et al., 2025).

Table 1: Summary of variables, their measurements, and data sources

Variable	Indicator	Assessment	Source
CO_2	Carbon dioxide emissions (metric tons per capita)	Dependent variable	WDI
IT	International tourism receipts (current US$) or International tourist arrivals	Independent variable	WDI
AP	Air transport, passengers carried	Independent variable	WDI
REC	Renewable energy consumption (% of total final energy consumption)	Independent variable	WDI

3.3. Test of Stationarity

The stationarity of the time series data is, however, the first stage of the analysis, important for guaranteeing the reliability of the econometric model. Stationarity tests are performed with techniques like the Augmented Dickey-Fuller (ADF) tests (Hariyadi et al., 2025). The ADF test tests the null hypothesis of a unit root (implying non-stationarity), whereas the KPSS test examines the null hypothesis of stationarity. The conclusions from these tests give some hint as to the order of the integration of the variables, and so, help to select the ARDL model. A non-stationary time series with a unit root has to be differenced or transformed in some way before useful modeling can take place. On the other hand, the confirmation of stationarity provides for an immediate use of the ARDL model without further option of transforming the data, which leads to credible inference on the connections between international tourism air transport and CO_2 emissions (Kuok et al., 2024).

3.4. Cointegration Test

After stationarity of the series has been checked, the cointegration test is the next step to determine whether there is any long-run relationship among the variables. In this study, we use the ARDL bounds testing cointegration, which tests to find the levels of integration between the variables, be it I(0) or I(1) (Hariyadi et al., 2025). This approach is based on estimating the ARDL model and then testing whether the F-statistic is significant against critical values from (Pesaran et al., 2001). If F F-statistic is greater than the critical value, this implies cointegration; Thus, the variables tend to move in the long run together (Hariyadi et al., 2025). Alternatively, a value of the F-statistic lower than the lower bound indicates that there is no cointegration. Evidence of cointegration will help with further investigation of short-run and long-run dynamics in international tourism, air transport, and CO_2 emissions in the relationship.

3.5. Stability Test

To check the stability of the ARDL model estimates, a stability test is also carried out, based on the Cumulative Sum (CUSUM) test that examines the stability of regression parameters over time (Hariyadi et al., 2025). This testing procedure is based on checking the recursive residuals of the estimated ARDL Relation. If the integrated sum of the recursive residuals falls within a set of determined critical bands, it supports parameter stability; if it falls outside these bands, it indicates structural instability in the

Figure 1: Analytical steps and a visual representation

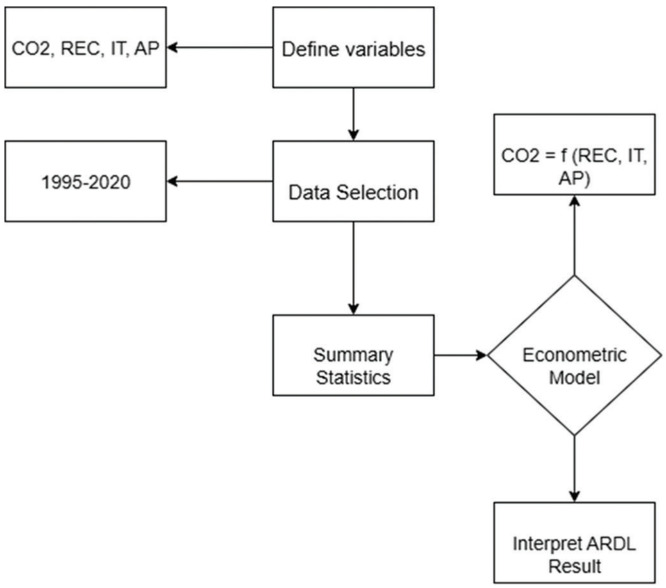
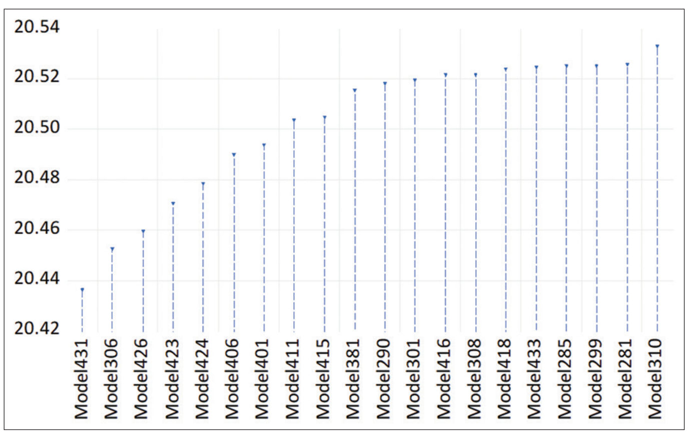


Figure 2: Akaike information criteria



model. It is important to identify stability because an unstable model provides unreliable estimates of (Shao et al., 2024). The CUSUM test for stability in this study also contributed to the quality of the findings, which allows researchers to make the right inferences about long-run linkages among international tourism, air transport, and CO_2 emissions in Thailand. Analytical steps and visual representation of the model is presented in Figure 1.

4. RESULTS AND DISCUSSION

The findings based on the ARDL model give us a more complicated portrait of the foreign tourism and aviation effects on CO_2 emissions in Thailand. More in particular, the model shows that for higher outbound international tourism, a notable decrease in CO_2 emission per tourist, which results in a decrease in environmental load per tourist, due to the reduction of the economy under some economic conditions (Bahar and Demir, 2023). Based on Table 2, the variables CO2, IT, and REC are non-stationary at their levels but become stationary after the first difference. In contrast, the variable AP is already stationary at its level. This outcome is

Table 2: Unit root test results

Variables	Level	First difference
CO_2	0.5840	0.0001*
AP	0.0031*	0.9209
IT	0.1955	0.0361*
REC	0.3152	0.0009*

consistent with previous research in the literature that argues that the more tourism presence and more positive it can lead the way for sustainable practices, influence the consumer behavior towards eco-friendliness and influence policymakers for protecting the environment.

AIC graph (Figure 2) of the best 20 ARDL models that were tested = height of each bar represents AIC value. When using AIC for the purpose of model selection, the goal is to select the model with the lowest AIC value, which represents the best trade-off between model fit and model parsimony. In the present graph, "Model431" has the minimum AIC, indicating that "Model431" is the best model among the other 20 models in this figure. Although the graph showed these models to be the best-scoring ones, it is important to remember that the ARDL fit you displayed was something like ARDL(1, 2, 0), or ARDL(1, 2, 3, 4) for another fit. This implies that the AIC graph serves as an initial screen or a former run of model selection, and the model the final model (ARDL(1,2,0) or ARDL(1,2,3,4) of your regression outputs) would be the one to be used for the inferences in the extensive ARDL estimation process.

The chosen ARDL(1,2,3,4) model for CO_2 emissions has a strong explanatory capability, with an Adjusted R-squared of 0.971397 and a highly significant F-statistic ($P < 0.000002$) (Table 3). The first lag of CO_2 (CO_2 (−1)) is not statistically significant ($P = 0.3534$), indicating no strong short-term dependence in CO_2 itself in this particular model form. In contrast, there is a consistent and significantly negative effect of International Tourism (IT) on CO_2 emissions the contemporaneous IT period (IT, $P = 0.0362$) as well as second lag (IT(−2), $P = 0.0523$), and first lag (IT(−1), $P = 0.0739$) are significant at the 5% and 10% level, respectively. Regarding REC, we only find that the current period (REC, $P = 0.0674$) is marginally significant, which suggests a less robust short-term relationship when compared to IT. AP series has an appreciable positive effect in the short run1 in the current period (AP, $P = 0.0183$) and with all its lags being significantly zero. Lastly, the C term is also strongly significant ($P = 0.0058$). Although the overall model fit is strong, the significance of the reported P-values may be substantially overstated, given that the automatic model selection process likely induces bias.

In contrast, the volume of air passengers displays a significant and positive association with CO_2 emission, especially during this period, highlighting the high dependence on airplanes in the tourism industry as a significant contributor to the emission. This in itself is a formidable dilemma for government planners intent on weighing the advantages of tourism against national (and global) requirements to reduce emissions. The difference between the impacts of international tourism and air transport opens up a complex in managing the ecological impact of tourism, indicating that benefits from focused interventions on air travel may be needed (Yaacob et al., 2023). It is worth mentioning that the high explanatory power of the ARDL (Adjusted R-squared of 0.971397) indicates that this model has a strong relationship among the variables; however, we should take care about P-values due to the possible influence of the model selection approach applied in this study (Azam et al., 2020). Although robust in nature, the results contribute to the comprehension of the relationship between tourism and environmental settings in Thailand and caution in the interpretation of the relationship between tourism expansion and CO_2 emission dynamics. This study in a general context provides important perspectives on the tourism-environment relationship in Thailand and calls for a dual policy regime from the perspective of expansion of tourism, and at the same time, ensuring sustainability in the sector. Also, a longitudinal approach to examine the persistence of the effectiveness of these interventions in reducing emissions and sustaining economic growth through tourism, over time, may be a direction for future research (Ozturk et al., 2023).

Figure 3: Stability test result

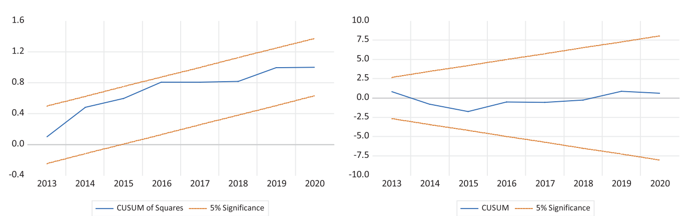


Table 3: ARDL result

Variable	Coefficient	P-value	Significance (%)
CO_2 (−1)	0.218629	0.3534	Not significant
IT	−10921.65	0.0362	Significant (5)
IT(−1)	−11629.50	0.0739	Marginally significant (10)
IT(−2)	−10972.67	0.0523	Marginally significant (10)
REC	−4.396.977	0.0674	Marginally significant (10)
REC(−1)	−3.219.748	0.3275	Not significant
REC(−2)	−2.462.186	0.4496	Not significant
REC(−3)	−4.663.275	0.1883	Not significant
AP	0.001356	0.0183	Significant (5)
AP(−1)	−0.000776	0.4085	Not significant
AP(−2)	0.000662	0.4800	Not significant
AP(−3)	−0.000244	0.8033	Not significant
AP(−4)	0.001350	0.1555	Not significant
C	576990.1	0.0058	Significant (1)

Table 4: ECM results

Variable	Coefficient	P-value	Significance (%)
D (IT)	−10921.65	0.0025	Significant (1)
D (IT(−1))	10972.67	0.0151	Significant (5)
D (REC)	−4.396.977	0.0089	Significant (1)
D (REC(−1))	7.125.461	0.0102	Significant (5)
D (REC(−2))	4.663.275	0.0175	Significant (5)
D (AP)	1.356	0.0007	Significant (1)
D (AP(−1))	−1.768	0.0046	Significant (1)
D (AP(−2))	−1.106	0.0469	Significant (5)
D (AP(−3))	−1.350	0.0298	Significant (5)
CointEq(−1)*	−0.781371	0.0003	Significant (1)

Table 5: F-bounds test results

Test statistic	Value	Signif. (%)	I (0)	I (1)
F-statistic	4.804.265	10	2.37	3.2
k	3	5	2.79	3.67
		2.5	3.15	04.08
		1	3.65	4.66

The Error Correction Model (ECM) regression results reveal both short-run dynamics and the adjustment mechanism towards long-run equilibrium. The statistically significant and negative coefficient of CointEq(−1) (−0.781371 with a P = 0.0003) is crucial as it confirms the existence of a long-run cointegrating relationship among the variables (Table 4). The value of −0.781371 implies that approximately 78.14% of the short-run disequilibrium in CO_2 is corrected or adjusted back towards the long-run equilibrium within one period. Meanwhile, the variables in first difference form (D) indicate short-run impacts. D(IT) and D(IT(−1)) are significant, suggesting that changes in international tourism have complex short-run effects on CO_2. D(REC), D(REC(−1)), and D(REC(−2)) are also significant, indicating that changes in renewable energy consumption have clear short-run impacts on CO_2 emissions. Similarly, D(AP), D(AP(−1)), D(AP(−2)), and D(AP(−3)) are all significant, implying that changes in air passenger numbers dynamically influence CO_2 emissions in the short run.

The F-bounds test (Table 5) is employed to examine the presence of a long-run cointegrating relationship between the variables. The null hypothesis (Null Hypothesis: No levels relationship) posits that no such long-run relationship exists. With an F-statistic value of 4.804265 and k (the number of independent variables) equal to 3, we compare this F-statistic to critical values at different significance levels. Since the calculated F-statistic (4.804265) is greater than the upper bound (I(1)) critical values at the 1% (4.66), 2.5% (4.08), 5% (3.67), and 10% (3.2) significance levels, we can strongly reject the null hypothesis. This rejection robustly confirms the existence of a stable long-run cointegrating relationship among the dependent variable (CO_2) and the independent variables (IT, REC, AP). This implies that, despite short-run fluctuations, these variables tend to move together towards a long-run equilibrium.

The graph used, which is assumed to be based on a CUSUM test (which stands for "Cumulative Sum of Recursive Residuals"), serves to control for the stability of the parameter estimates of the estimated ARDL model. According to Figure 3, the blue line corresponds to the CUSUM statistics, and the two orange dashed lines correspond to the 5% significance bounds. The blue line corresponds to the CUSUM statistics, and the two orange dashed lines correspond to the 5% significance bounds. The CUSUM line needs to be between these two critical lines for the model to be stable. For this example, the CUSUM line remains entirely within the 5% significance bounds during the entire monitoring period. This implies that the estimated ARDL model parameters do not exhibit significant time-variation and that the model is correctly specified so that its forecasting ability is trustworthy, as no significant structural breaks or shifts in the underlying relationships among the variables are reported.

5. CONCLUSION

Overall, this research reveals the complex interplay among international tourism, air travel, CO_2 emissions, and economic expansion in Thailand. The results indicate that international tourism works both ways in CO_2 emissions in a sustainable tourism development and environmental management context. On the contrary, although the number of air passengers is positively associated with CO_2 emissions in the current period, their contribution relative to the total international tourism amounts to a policy-target implication. This indicates that although higher numbers of tourists can result in more sustainable operations, the operation of air travel in itself requires attention and innovation to reduce its environmental impact.

Recognizing these contributions, it is important to note some limitations of the study, notably its reliance on aggregate data that may conceal variations in the environmental impact of tourism at the regional level. Future studies need to analyze data by disaggregation, and a mixed-method research with qualitative information and quantitative data combined must be applied to assess the changing dynamics of the interactions at the local level. Moreover, as Thailand continues down the path of post-pandemic recovery, understanding how the COVID-19 pandemic has affected tourism flows and CO_2 emissions could help devise future strategies that are more resilient. This sense of urgency behind the shift to a more sustainable tourism model couldn't be greater, not only to help in the preservation of the country's immaculately rich ecology and landscapes, but also to counter the tide against climate change. At the end of the day, not only does it help in boosting the economy, but it also helps to encourage more environmentally sound frameworks that allow the locals to get involved, all the while pushing for widespread systemic changes that bring advantages to everyone involved in the tourism industry.

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